ENGINEERING PROPERTIES OF WARM MIX ASPHALT USING SYNTHETIC ZEOLITE AS AN ADDITIVE

A project submitted in partial fulfillment of the requirements for the degree of

Bachelor of technology

In

Civil Engineering

By

SOURAV KUMAR SAHOO

(109CE0090)

Under the guidance of

Prof. MAHABIR PANDA

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA-769008

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

Certificate

This is to certify that the thesis entitled "**ENGINEERING PROPERTIES OF WARM MIX ASPHALT USING SYNTHETIC ZEOLITE AS AN ADDITIVE**" submitted by SOURAV KUMAR SAHOO in partial fulfillment for the requirement for the award of Bachelorin Technology degree in Civil Engineering at National Institute of Technology, Rourkela, is an authentic work carried out by him under my supervision and guidance.

To the best of myknowledge, the content in this thesis has not been submitted to any otherUniversity/Institute for the award of any degree or Diploma.

Prof. Mahabir Panda

Department of Civil Engineering

National Institute of Technology

Rourkela-769008

ACKNOWLEDGEMENTS

I am heartily thankful to my guide **Prof. Mahabir Panda**, Department Of Civil Engineering, National Institute of Technology, Rourkela and extend my deep sense of gratitude for his encouragement, guidance and support from the initial to the final level that enabled me carrying out my project work.

I am extremely grateful to **Prof. Ramakar Jha**, faculty advisor and Prof**. N Roy,** Head of the Department of Civil Engineering and members of Civil Engineering Department, National Institute of Technology, Rourkela, for providing all kind of possible help throughout the B.Tech Final year for the completion of this project work. I would like to thank to **Mr. H. Garnayak,** Lab Attendant,for their great support in carrying out the experiments.

I would also like to thank the M tech students of Transportation Engineering, Department Of Civil Engineering, National Institute of Technology, Rourkela for their kind support in my Project work.

Lastly I would like to thank my parents, my fellow classmates and my friends for their kind support and encouragement during my study.

SOURAV KUMAR SAHOO

(109CE0090)

ABSTRACT

Warm mix asphalt(WMA) is a recent technology used to reduce the mixing and compactiontemperatures without affecting the quality of pavement. Warm mix asphalt is a bituminous mixture where all its constituents are mixed, placed, compacted at medium temperature .A number of WMA processes havebeen developed in recent days. One of the processes includes the use ofsynthetic zeolite as anadditive.An attempt has been made in the laboratory to develop warm mix asphalt mixes using synthetic zeolite asan additive at a specified mixing and compaction temperature which were obtained after a number of trials.Thestone matrix asphalt (SMA) and dense bituminous macadam (DBM)mixes with aggregate gradation as per MORTH specifications were made with varying bindercontents (5%,6% and7%). The zeolite content was 0.3% by weight of aggregate. Stone dust and cement were used as filler for SMA andDBM samples respectively. VG 30 grade bitumen was used as binder for both the mixes.Marshall procedure has been made for preparation of samples and evaluation of bituminous mixes. The volumetric properties (VA, VMA and VFB), stability, flow value and optimum binder content of the SMA and DBM mix samples have beeninvestigated. The optimum binder content ofthe DBM and SMA samples was found to be 5.3% and 5.8% respectively.

Table of contents

Chapter 2: Literature Review

Chapter 3: Materials Used

Chapter 4:Experimental procedure

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

WMA-Warm mix asphalt

HMA-Hot mix asphalt

SMA-Stone matrix asphalt

DBM-Dense bituminous macadam

Gsb – Bulk specific gravity of aggregates

Gse – Effective specific gravity of aggregates in mix

Ga – Apparent specific gravity of aggregates

Gmm – Theoretical maximum specific gravity of the mix

Gmb – Bulk Specific gravity of the mix/ unit weight

VMA – Voids in mineral aggregates

VA – Air void

VFB – Voids filled with bitumen

Bvs – Bulk volume of sample

CHAPTER 1

INTRODUCTION

1.1INTRODUCTION

A number of processes have been developed to reduce the mixing and compaction temperature of hot mix asphalt(HMA). The mixing and compaction temperature of HMA usually range from 275-325 F. Its use in pavement of roads leads to large consumption of energy and emission of green house gases and other pollutants to atmosphere. Warm mix asphalt is a recent technology used for pavement of roads which utilises relatively low mixing and compaction temperature than HMA. Its use in pavement of roads reduces energy consumption,green house gas emission and asphalt oxidation.It also increases paving season and hauling distance for a better work environment.

1.1.1. HISTORY OF WMA

Although new to the Pacific Northwest, WMA has been used in Europe successfully formore than 15 years. In 2002, the National Asphalt Paving Association first brought warm mixasphalt technology to the United States and generated significant interest in the U.S. market.Recently the Federal Highway Administration and National Asphalt Paving Association formed the WMA Technical Working Group, whose aim is to check and validate WMA technologies and to implement WMA policies and practices that contribute to a high quality and cost effective transportation infrastructure. As a result of this, various WMA projects have been tested across the United States and recent topics of research includes long term performance,thermal cracking, short and long term aging effects, and additive usage and performance grade binderspecifications.

1.1.2. WMA TECHNOLOGIES AVAILABLE

Recently various technologies available to increase the workability at lower temperatures forthe production of WMA. Most technologies involve the addition of chemical or plain water additivesto emulsify or foam the oil, allowing a reduction in viscosity and an evenly coating of the aggregate mix.

Any of the following WMA technologies can be used:

• Organic additives (including waxes)

• Water-bearing zeolites

• Water-based foaming processes

• Emulsion-based processes

1.1.3 .IMPORTANCE OF USING WMA

The importance of using WMA can be categorized into 3 categories: economic, operational and environmental :

>>Reduced Fuel Consumption:

The main advantage of WMA is the reduction of mixing and compaction temperatures as compared to HMA, there is significant reduction in the usage of fuels.

>>Late season paving:

Since WMA is compacted at lower temperatures , the mix can be produced at lowertemperatures and can therefore remain compactible for a longer period of time.

>>Better Workability and Compaction:

WMA provides better workability at lower temperatures due to the addition of additives. Better workability also results in better compaction.

>>Reduced Emissions of Greenhouse Gases:

By using WMA it is possible to reduce the gaseous emissions since the quantity of fuel used in WMA is significantly less.

>>Better Working Conditions:

The reduction in the mixing and compaction temperature causes a visible reduction in the smoke and odor and may thus result in improved working conditions.

1.1.4. SYNTHETIC ZEOLITES AS ADDITIVES:

Zeolites are crystalline, micro porous and hydrated aluminosilicates that are built from an infinitely extending three dimensional network of [SiO_4] and [AlO_4] tetrahedral linked to each other by the sharing of oxygen atoms. Usually, their structure can be considered as inorganic polymer built from tetrahedral TO_4 units, where T is Si4+ or Al3+ ion. Each O atom is shared in betweentwo T atoms.**(5)**

Zeolites are silicate frameworks with structures having large empty spaces,that can include large cations such as calcium and sodium. These empty spaces may also allow the presence of large cation groups such as water molecules. Zeolites have the property to lose or absorb water without any change in crystal structure.Heat releases the water present in zeolites.When zeolite is added to the mix as the binder,water gets released. This released water creates an expansion of binder that results in foaming of asphalt and increase in workability. This also helps in coating of aggregates at lower temperature.**(5)**

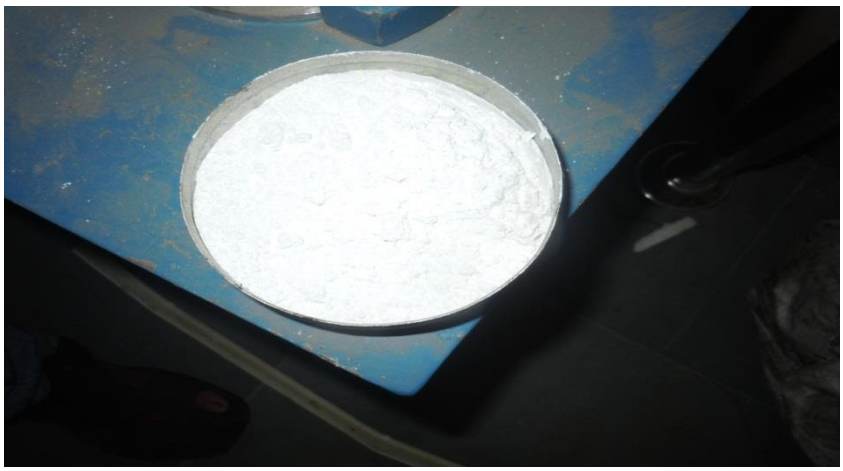

Fig 1.3: Synthetic zeolite used

1.2OBJECTIVES:

>>To prepare warm mix asphalt (WMA) samples of stone matrix asphalt (SMA) and dense bituminous macadam (DBM) mix with syntheticzeolite as an additive at different binder contents at 110 ℃.

>>To evaluate the engineering properties and performances of WMA samples through Marshall test.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTON

In 1997, at the Bitumen Forum of Germany warm mix asphalt (WMA) technology (3) was identified as one of means to lower emissions. In 2002, the WMA technology was introduced in the United States. It was this time when the NAPA sponsored an industry scanning tour to Europe for asphalt paving contractors.

The World of Asphalt convention in 2004 featured a WMA demonstration project,after which the manufacturers of WMA additives have successfully demonstrated many projects throughout the United States.

Hurley and Prowell,**2005**(a,b,c) (8, 9, 10) evaluated three different WMA additives: Aspha-Min®(synthetic zeolite), Sasobit®(wax) and Evotherm™(emulsion) and concluded that all three technologies improved the asphalt mixture compatibility and resulted in reduction of air voids as compared to HMA.They stated that the addition ofAspha-min lowered the air voids in WMA measured in the gyratory compactor. This can also improvethe compactability of both the gyratory compactor and a vibratory compactor. Statistical analyses of test results indicated an average reduction in air voids of 0.65% using the vibratory compactor.Aspha-min did not have any significant effect on the resilient modulus of asphalt mixtures.WMA with the addition of Aspha-min successfullyincorporated ahigher percentage of RAP materials thanHMA. Aspha-min was added to a Superpave mixture containing 20% RAP during a demonstration project in Orlando, Florida. The addition was able to reduce the production and compaction temperatures by 20 °C, while yielding the same in-place density.

Hurley and Prowell, **2006**(11) reported that, the rutting potential was not increased based on wheel-tracking test with these three WMA additives Aspha-Min® (synthetic zeolite), Sasobit®(wax) and Evotherm™(emulsion).The low compaction temperature used while producing warm asphalt with the addition of Aspha-min may increase the potential for moisture damage. Low mixing and compaction temperatures can result in incomplete drying of the aggregate and the water trapped in the coated aggregate may cause moisture damage. . The addition of 1.5% hydrated lime has resulted in acceptable performance, in case of both cohesion

and moisture resistance, that was better than the performance of warm mixtures without hydrated lime.

Prowellet al., 2007 reported that the WMA test sectionswhich were accelerated exhibited the excellent field performance in terms of rutting.

Goh et al., 2007,(6) evaluated the properties of WMA with the addition of Aspha-min (synthetic zeolite) based on the Mechanistic-Empirical Pavement Design Guide (MEPDG). They found that the addition of Aspha-min did not have any effect on the dynamic modulus values for any of asphalt mixtures examined.The rut depths predicted from the MEPDG simulations showed that WMA could decrease rutting and the greatest difference of rutting between WMA and its control could be up to 44%.

Lee et al.,(2008),(18) prepared three types of CIR-foam specimens: (a) CIR-foam with 1.5% of Sasobit® (wax), (b) CIR-foam with 0.3% Aspha-min® (synthetic zeolite),and (c) CIR-foam without any additive. They reported that WMA additives have improved the CIR-foam mixtures compactibility resulting in reduction of air void. The indirect tensile strength of CIR-foam mixtures with Sasobit®(wax) was the highest. Flow number of CIR-foam mixtures with Sasobit® was the highest followed by ones with Aspha-min®(synthetic zeolite), and the specimens without any additive.

Wielinski et al.,2009 (22) conducted a study based on laboratory tests and field evaluations of foamed WMA. They found that the Hveem and Marshall properties of HMA and WMA were almost similar, and all met the Hveemdesign requirements and the mixture property requirements. The in-situ densities were also almost similar.

Hodo et al.,2009 (7) stated that the foamed asphalt mixturespresented better workability at lower temperatures which showed greater ease in placingand compacting it and the moisture susceptibility tests showed marginal results and they suggested that if anti-stripping agents were added to theWMA mixture, the moisture damage resistance would be improved.

2.2. CONCLUDING REMARKS

As per literature review, various binder properties affect the performance ofthe warm mix technologies (WMA) differently. The aggregates also have definite effect on the moisture susceptibility, rutting potential and resilient modulus of WMA in a different manner. Therefore, a thorough understanding of the properties and performance of the warm mixture technologies is required in order to implement it safely. Theuse of different additives affects the workability and performance of WMA differently. Research conducted on warm asphalt so far has been on the mixtureproperties (Hurley and Prowell, 2006; Barthel, et al.; Hurley and Prowell, 2005) andnot much has been on the binder properties of warmasphalt. The review of the literature gives us the idea about the effect of temperature in the preparation of warm mix and use of synthetic zeolite as an additive. In this laboratory investigation of WMA, SMA and DBM aggregate gradation as per MORTH specifications andVG 30 bitumen was used as binder.

CHAPTER3

MATERIALS USED

3.1. Aggregates:

Both coarse and fine aggregates are required for the sample preparation. The aggregates are crushed by using crusher to get varying size of aggregates from 16mm to 75micron. The coarse aggregate should consist of crushed rocks retained on a 2.36 mm sieve. It should be clean, cubic shaped and rough texture to resist rutting and movements and hardness which can resist fracturing under heavy traffic loads.

The fine aggregate shall consist 100% of fine crushed sand passing the 2.36 mm sieve and retained on 0.075mm sieve. Preferably it should be clean, hard, durable, cubical in shape and free from soft pieces.

3.1.1.Test for aggregates:

1. **Impact Value Test (BIS 2386 -Part1):**The aggregate impact value indicates a relative measure of resistance of aggregate to impact.The aggregate impact value should be less than 18%.Aggregate impact value = (B/A) x 100 , WhereB=weight of fraction passing 2.36-mm IS Sieve andA =weight of oven-dried sample.

2. **Crushing Test (BIS 2386 -Part1):**This test value provides a relative measure of resistance to crushing under gradually applied crushing load. Aggregate crushing value = (B/A) x 100 , Where B= weight of fraction passing the appropriate Sieve, andA = weight of surface-dry sample.

3. **Los Angel's abrasion Test (BIS 2386 -Part1):**The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of 20 to 33 rev/min. The machine shall be rotated for 500 revolutions. Thedifference between the original weight and the final weight of the test sample shall be expressed as a percentage of the original weight of the test sample and this value shall be reported as the percentage of wear/abrasion value. Los Angel's abrasion value should be less than 25%.

4. **<u>Flakiness and Elongation Index (BIS 2386 -Part1)</u>:** The elongation index is the percentage by weight of the materials whose greatest dimension is greater than 1.8 times of their mean dimension. The flakiness index is the percentage by weightof the materials whose least dimension is less than 0.6 times of their mean dimension.

The physical properties of the mineral aggregates as obtained from testing of Impact value, crushing value, flakiness index,elongation index and Los Angeles abrasion value test for the stone aggregates

Table 3.1: Physicalproperties of stone aggregates.

Test description	Coarse aggregates	Fine aggregates	Standard values
Flakiness index (%)	18	-	< 20
Elongation index (%)	13	-	<15
Specific gravity	2.76	2.64	2.6-2.9
Los Angeles abrasion value (%)	24.4	-	< 30
Impact value (%)	17.4	-	< 18
Aggregate Crushing value (%)	18	-	<30
Angularity number	10	-	0-11
Water absorption	0.8	-	1.3

3.1.2 Grading of aggregates:

The gradation of aggregate was taken as per MORTH specification:

Table 3.2 Gradation of aggregates for stone matrix asphalt

BIS Sieve	% passing (range)	% passing (adopted)
26.5	-	-
19	100	100
13.2	90-100	95
9.5	50-75	62.5
4.75	20-28	24
2.36	16-24	20
1.18	13-21	17
0.6	12-18	15
0.3	10-20	15
0.075	8-12	10
Binder Content (%)	5-7	5-7

3.2 BITUMEN:

Bitumen is used as a binder in SMA and DBM mix.. The various characteristics of bitumen that affects the bituminous mix behavior are susceptibility to temperature, visco-elasticity and aging. The behavior of bitumen depends on temperature and also on the time of loading. It is stiffer at low temperature and under a short loading period. Bitumen must be treated like a visco-elastic material as it shows both viscous and also the elastic properties at normal pavement temperatures. Even though at low temperature it behaves as if it was an elastic material and at high temperature its behavior is like a viscous fluid. For preparation of SMA and DBM mix samples we used VG30 grade bitumen.

Table 3.3 Gradation of aggregates for dense bituminous macadam

BIS Sieve	% passing (range)	% passing (adopted)
26.5	100	100
19	90-100	95
13.2	56-88	72
4.75	16-36	26
2.36	4-19	11.5
0.3	2-10	6
0.075	0-8	4
Bitumen content (%)	4-7	4-7

3.2.1. Test for bitumen

1. Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds.

2. Ductility test

Ductility is the property of bitumen that permits it to undergo great deformation. Ductility isdefined as the distance in cm to which a standard sample or briquette of the material will be elongated withoutbreaking.

3. Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. This test is conducted by using the Ring and Ball apparatus.

4. Specific gravity test

The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27ºC. It can be measured using either pycnometer or preparing a cube specimen of bitumen in semi solid or solid state.

Table 3.4 Properties of bituminous binder

Test description	Results	Standard values (MORTH)
Penetration at 25ºC (1/10 mm)	65	50 to 70
Softening point ºC	65.2	>47 ºC
Ductility, cm	> 90	-
Specific gravity	1.08	-

Fig3.1VG30 grade bitumen used

3.3SYNTHETIC ZEOLITE: It is used as an additive in warm mix asphalt sample preparation.The quantity of zeolite used for SMA and DBM samples is 0.3% by the weight of total aggregates. The color is white and its specific gravity was 2.3.

3.4 FILLER: Filler is used in mixes for better binding of materials.Stone dust is used as filler for SMA Mix and cement is used as filler for DBM mix.

Mineral fillers have significant impact over the properties of SMA and DBM mixes:

- Mineral fillers tend to increase the stiffness of the asphalt and mortar matrix.
- Mineral fillers also affect the workability, aging characteristics and moisture resistance of mixtures.
- Mineral fillers help to reduce the drain-down in the mix during construction which improves the durability of the mix by properly maintaining the amount of asphalt used in the mix.
- It also helps in maintaining adequate amount of void in the mix

Table 3.6 : Specific gravities of material components

Specific Gravity					
Bitumen	Coarse Aggregate	Fine Aggregate	Cement	Stone dust	synthetic zeolite
1.08	2.75	2.75	3.15	2.63	2.3

Chapter 4

EXPERIMENTALWORKS

4.1Sieve analysis

Sieve analysis was done and aggregates of appropriate sizes were collected and stored in place with sizes as per IRC gradation for SMA and DBM mix.The coarse aggregate, fine aggregate, and the filler should be mixed according to specified proportion so as to fulfill the requirements.

4.2Sample preparation

4.2.1Weighing of sample

For SMA, 3 samples for each binder contentof 5%, 5.5%, 6%, 6.5% and 7% were prepared. For DBM mix, 3 samples for each binder content 4%, 5%,6% and 7% were prepared.The sample weight was recorded.

4.2.2 Aggregate heating

For particular binder content,SMA and DBM samples were heated at 110℃for 2 hours in oven. An overheating of sample was avoided.

Fig 4.1: Heating of aggregates and filler mixture in oven

4.2.3Bitumen heating

At a high temperature, VG30 bitumen was heated to melt down and liquefy which would be used for mixing.

Fig 4.2: Heating of binder

4.2.4Mixing

All components (aggregate, filler, bitumen and zeolite) are mixed properly to make a homogeneous SMA and DBM mixture.

Fig 4.3: Mixing of aggregates, bitumen, zeolite and filler

4.2.5Placing in mould

For preparation of samples, the mixture prepared was put in moulds. The mould is a cylindrical mould made of iron having a diameter of 10 cm.

Fig 4.4: Marshall Mould

4.2.6 Compaction with standard hammer

After putting in mould, hammering was done. A standard hammer was used. Usually hammering was done by giving 75 blows to each side of specimen. In this research each sample was given 75 blows each on both faces. For hammering, mould was attached to a fixed arrangement to make sure thatmould is not moved during hammering. A piece of paper was putin the mouldover-fitting so that mix is not stuck to arrangement.

Fig 4.5: Hammer used for compaction

4.2.7.Removing sample from mould

After the sample is cooled down, it is removed from the mould very carefully.Now stickering of each sample is done for distinguishing purpose.

Fig 4.6: Sample left to cool down

4.3 Measurement of Physical properties:

Now dryweights of samples were measured. Weight of sample in water is also required. Because sample has voids so water may enter in voids. To prevent that wax was melted and was coated around the sample by immersing the sample in wax container by holding it through a thread. Once the sample was dipped fully in wax it is allowed to cool so that wax is sticked to sample properly.After wax coating the weight of waxed sample is measured. Now weight of sample in water is also recorded. After all this, the sample is put in water bath before testing upto a maximum of ½ hours. In water bath temperature of 60 ℃ is maintained throughout. If sample is heated more, then the wax may get stripped off. So overheating is avoided.

Fig 4.7: Samples before and after wax coating

Fig 4.8: Samples kept in hot water bath

4.4 MARSHALL TEST

This test is performed to measure the resistance to plastic deformation of a compacted cylindrical sample of bituminous mixture when the sample is loaded diametrically at a deformation rate of 50 mm / minute. There are two major features of the Marshall method of mix design, (i) density-voids analysis and(ii) stability-flow tests. The stability of the mix is defined as the maximum load in KN carried by the specimen at a standard test temperature of 60°C and the flow value is the deformation that the sample undergoes during loading upto the maximum load. Flow value is measured in 0.25 mm units.

4.4.1.PROCEDURE:

1.The rods and inner surfaces of the test head segments prior to conducting the test are thoroughly cleaned.

2. Guide rods are lubricated so that the upper test head segment slides freely over them and excesswater from the inside of the head segments is wiped off.

3. A sample from the waterbath is removed and placed in the lower segment of the testing head. The upper segment of the testing head is placed on the sample and the complete assembly is paced in position in the loading machine.

4. Then the dial gauge is placed in position over one of the guide rods. The time elapsed from removal of the test specimens from the water bath to the final load determination should not exceed 30 s.The readings of dial gauge and proving ring are recorded. In this case 36 divisions of proving ring were equal to 100 kg.

Fig 4.9:Marshall test apparatus

Fig 4.10: Marshall test being conducted with the Marshall apparatus

CHAPTER5

TEST RESULTS AND DISCUSSION

5.1.WEIGHTS AND SPECIFIC GRAVITIES: After the sample is prepared , its weight before wax coating, weight after wax coating and weight in water is taken.From these values, bulk volume of the sample,bulk specific gravity of the aggregates,effective specific gravity of the aggregates in mix,theoretical maximum specific gravity of the mix,bulk Specific gravity of the mix,voids in mineral aggregates,air void and voids filled with bitumen. The specific gravity of wax is taken as 0.9 g/cc approximately and specific gravity for water it is taken as 1 g/cc .So for the analysis of results, we need to deal with some basic abbreviations.

5.1.1 MARSHALL STABILITY

Stability of a mix is obtained after deciding the load taken by the sample and after that multiplying by a suitable factor called as the correlation ration which is obtained by comparing the thickness/ height of the sample or the volume of the sample. On increasing bitumen content the stability value, increases up to some point theoretically and then falls.This is due to the reason that with the initial increase in bitumen content, the aggregate and bitumen bond gradually goes on getting stronger, but with any further increase in the content of bitumen, the applied load is transmitted. This transmission of load is through hydrostatic pressure, keeping that fraction across the contact point of aggregates immobilized. This makes the mix very weak against plastic deformation and hence the stability falls.

5.1.2 FLOW VALUE

Flow in general terms is defined as the deformation undergone by the sample at the condition of maximum load where failure usually occurs. The flow value increases with an increase in bitumen content for both cases of the mix with and without fibers .The increase is initially slow, but later the rate of increase of flow value increases with increase in bitumen content.

5.1.3 AIR VOIDS

During the process of casting of the sample, use air voids get in between the sample due to improper compaction and heating. The Air Voids (VA) decreases as we go on increasing the bitumen content. This is because with an increase in bitumen content bitumen fills the air voids continuously.

5.1.4 VOIDS IN MINERAL AGGREGATE

The value of VMA, for a given aggregate should remain constant theoretically. However, it is sometimes observed, that at low bitumen content, VMA keeps on slowly decreasing with an increase in bitumen content and then it remains constant, and finally increases with the higher bitumen content. The initial fall of VMA value is because of the reorientation of aggregates in the presence of the bitumen. At a high bitumen content, this is due to a thicker bitumen film, that repels the aggregates slightly apart increasing the VMA value theoretically.

5.2 OBSERVATION BASED ON PHYSICAL PROPERTIES:

Table 5.1 : Physical properties ofSMA samples

SAMPLE	TEMPERATURE (℃)	BITUMEN (%)	WEIGHT OF SAMPLE IN AIR gm)	WEIGHT OF SAMPLE AFTER PARAFFIN COAT(gm)	WEIGHT OF SAMPLE IN WATER (gm)	HEIGHT (mm)	RADIUS (mm)	WEIGHT OF AGGREGATE MIX (gm)
1	110	5	1195	1198	698	61	50	1140
2	110	5	1199	1212	696	61.5	50	1140
3	110	5	1198	1208	699	62	50	1140
1	110	5.5	1198.2	1202	707	63	50	1134
2	110	5.5	1196	1200	705	61	50	1134
3	110	5.5	1197	1200	703	63	50	1134
1	110	6	1192	1210	710	61	50	1128
2	110	6	1190	1212	708	61.5	50	1128
3	110	6	1196	1215	709	61	50	1128
1	110	6.5	1189	1218	717	60	50	1122
2	110	6.5	1188	1215	713	61	50	1122
3	110	6.5	1191	1210	715	62	50	1122
1	110	7	1191	1220	721	62	50	1116
2	110	7	1190	1219	723	60	50	1116
3	110	7	1189	1221	720	61	50	1116

Table 5.2 : Physical properties of DBM sample

SAMPLE	TEMPERATURE (℃)	BITUMEN (%)	WEIGHT OF SAMPLE IN AIR gm)	WEIGHT OF SAMPLE AFTER PARAFFIN COAT(gm)	WEIGHT OF SAMPLE IN WATER (gm)	HEIGHT (mm)	RADIUS (mm)	WEIGHT OF AGGREGATE MIX (gm)
1	110	4	1199	1204	707	63	50	1152
2	110	4	1196	1202	705	61	50	1152
3	110	4	1195	1200	703	63	50	1152
1	110	5	1190	1210	707	61	50	1140
2	110	5	1192	1212	710	61.5	50	1140
3	110	5	1196	1214	709	61	50	1140
1	110	6	1187	1218	717	61	50	1128
2	110	6	1188	1213	713	63	50	1128
3	110	6	1191	1215	714	60	50	1128
1	110	7	1188	1219	721	62	50	1116
2	110	7	1190	1219	723	63	50	1116
3	110	7	1189	1218	720	61	50	1116

Table 5.3: Weights and Specific Gravities of SMA samples

Binder (%)	Bvs	Gmb	Gsb	Vol	Gmm	VA	Avg. VA	VMA	Avg VMA	VFB	Avg VFB	Gse
5	496.667	2.406	2.762	479.093	2.588	6.033		17.229		64.175		2.762
5	501.556	2.391	2.762	483.020	2.588	6.632	6.231	17.761	17.404	60.702	65.023	2.762
5	497.889	2.406	2.762	486.947	2.588	6.029		17.224		69.192		2.762
5.5	490.778	2.441	2.762	494.801	2.588	5.051		16.011		68.279		2.762
5.5	490.556	2.438	2.762	479.093	2.588	4.797	4.720	16.127	16.24	68.057	68.760	2.762
5.5	493.667	2.425	2.762	494.801	2.588	4.312		16.586		69.944		2.762
6	480.000	2.483	2.762	0.000	2.588	4.528		16.889		72.223		2.762
6	479.556	2.481	2.762	483.020	2.588	3.119	3.781	14.634	15.56	71.852	71.860	2.762
6	484.889	2.491	2.762	479.093	2.588	3.696		15.147		71.505		2.762
6.5	468.778	2.436	2.762	0.000	2.588	3.222		16.827		74.480		2.762
6.5	472.000	2.481	2.762	479.093	2.588	2.748	3.287	14.913	15.76	72.512	73.880	2.762
6.5	473.889	2.496	2.762	486.947	2.588	3.891		15.540		74.648		2.762
7	466.778	2.430	2.762	0.000	2.588	3.412		15.97		75.451		2.762
7	463.778	2.426	2.762	471.239	2.588	2.857	3.090	16.21	16.14	76.231	74.998	2.762
7	465.444	2.455	2.762	479.093	2.588	3.001		16.24		73.312		2.762

Table 5.4: Weights and Specific Gravities of DBM samples

Binder (%)	Bvs	Gmb	Gsb	Vol	Gmm	VA	Avg. VA	VMA	Avg VMA	VFB	Avg VFB	Gse
4	491.444	2.440	2.762	0.000	2.588	5.731		16.069		64.334		2.762
4	490.333	2.439	2.762	479.093	2.588	5.754	5.83	16.089	16.16	64.238	63.86	2.762
4	491.444	2.432	2.762	494.801	2.588	6.046		16.349		63.022		2.762
5	480.778	2.475	2.762	0.000	2.588	4.363		13.883		68.342		2.762
5	479.778	2.484	2.762	483.020	2.588	4.003	4.12	14.530	13.86	67.453	68.23	2.762
5	485.000	2.481	2.762	479.093	2.588	3.994		13.167		68.895		2.762
6	466.556	2.544	2.762	0.000	2.588	3.294		14.305		72.329		2.762
6	472.222	2.556	2.762	494.801	2.588	2.994	3.09	13.954	13.96	70.234	70.89	2.762
6	474.333	2.538	2.762	471.239	2.588	2.982		13.621		70.107		2.762
7	463.556	2.512	2.762	0.000	2.588	2.976		13.836		71.750		2.762
7	463.778	2.516	2.762	494.801	2.588	2.857	2.78	15.121	14.38	72.691	72.09	2.762
7	465.778	2.502	2.762	479.093	2.588	2.507		14.183		71.829		2.762

5.3 OBSERVATIONS FROM MARSHALL TEST:

Table 5.5: Stability and Flow values of SMA samples

TEMP(℃)	BINDER (%)	STABILITY(KN)	AVERAGE STABILITY(KN)	FLOW (mm)	AVERAGE FLOW(mm)
110	5	10.66		2.4	
110	5	11.38	10.86	2.4	2.466
110	5	10.55		2.6	
110	5.5	11.97		2.8	
110	5.5	13.61	13.17	2.5	2.53
110	5.5	13.93		2.3	
110	6	10.83		2.9	
110	6	12.05	11.47	2.8	2.83
110	6	11.55		3	
110	6.5	9.16		3.3	
110	6.5	10.05	9.53	3.7	3.3
110	6.5	9.38		2.9	
110	7	9.55		4.5	
110	7	7.77	8.49	4.1	4.16
110	7	8.16		3.9	

Table 5.6: Stability and Flow values of DBM samples

TEMP. (°C)	BINDER (%)	STABILITY(KN)	AVERAGE STABILITY(KN)	FLOW (mm)	AVERAGE FLOW(mm)
110	4	10.55		2.1	
110	4	11.05	11.08	1.9	2.1
110	4	11.66		2.3	
110	5	13.36		2.3	
110	5	11.88	12.48	2.1	2.3
110	5	12.22		2.5	
110	6	10.16		3.3	
110	6	9.88	10.27	2.5	2.86
110	6	10.77		2.8	
110	7	9.88		4.2	
110	7	10.05	9.69	3.6	3.86
110	7	9.16		3.8	

5.4 RELATIONSHIPS:

1. Stability vs. bitumen content: Values of average stability number in KN and binder content in % are plotted against bitumen in x-axis and stability in y-axis.

- **Average stability and Bitumen content for SMA samples**

BITUMEN CONTENT (%)	Average stability (KN)
5	10.86
5.5	13.17
6	11.47
6.5	9.53
7	8.49

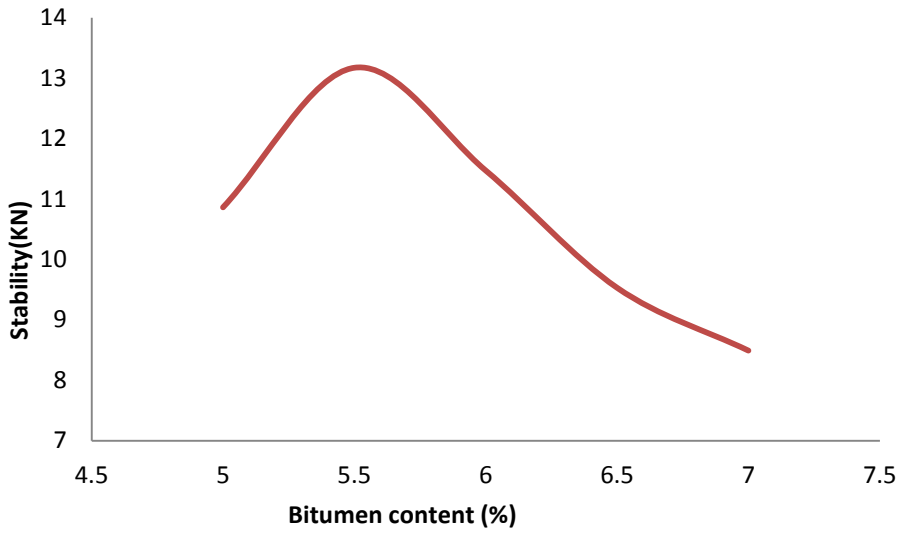

Fig 5.1: Average stability vs. Bitumen content for SMA samples

- **Average stability and Bitumen content for DBM samples**

BITUMEN (%)	Average stability(KN)
4	11.08
5	12.48
6	10.27
7	9.69

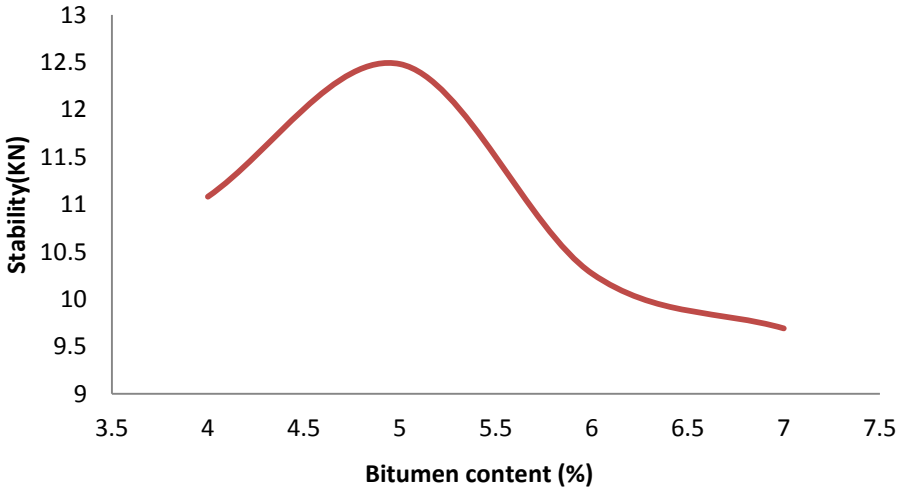

Fig 5.2: Average stability vs. Bitumen content for DBM samples

2. Flow value vs. bitumen content: Flow values in mm and bitumen content in %ge are plotted against binder in x-axis and Flow in y-axis.

- **Average flow value and Bitumen content for SMA samples**

BITUMEN CONTENT (%)	Average flow value(mm)
5	2.466
5.5	2.53
6	2.83
6.5	3.3
7	4.16

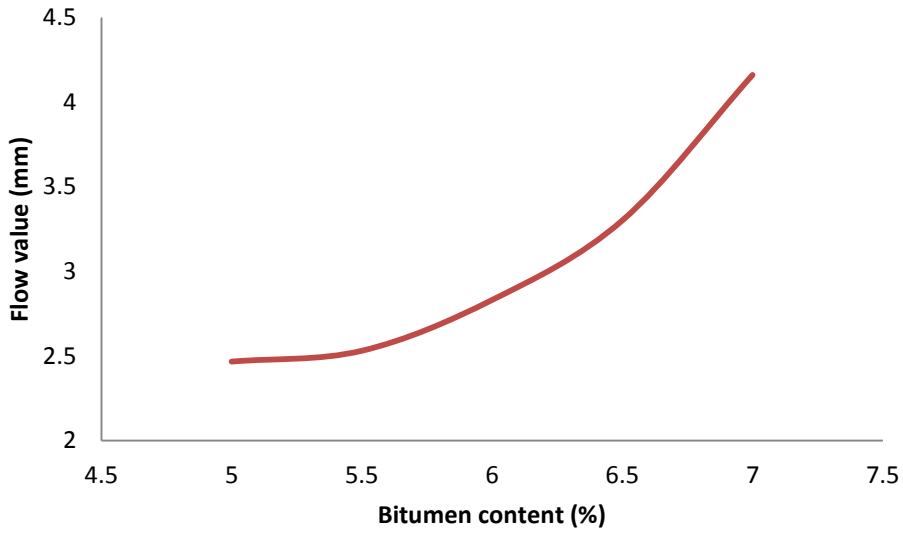

Fig 5.3: Average flow valuevs. Bitumen content for SMA samples

- **Average flow value and Bitumen content for DBM samples**

BITUMEN (%)	Average flow value(mm)
4	2.1
5	2.3
6	2.86
7	3.86

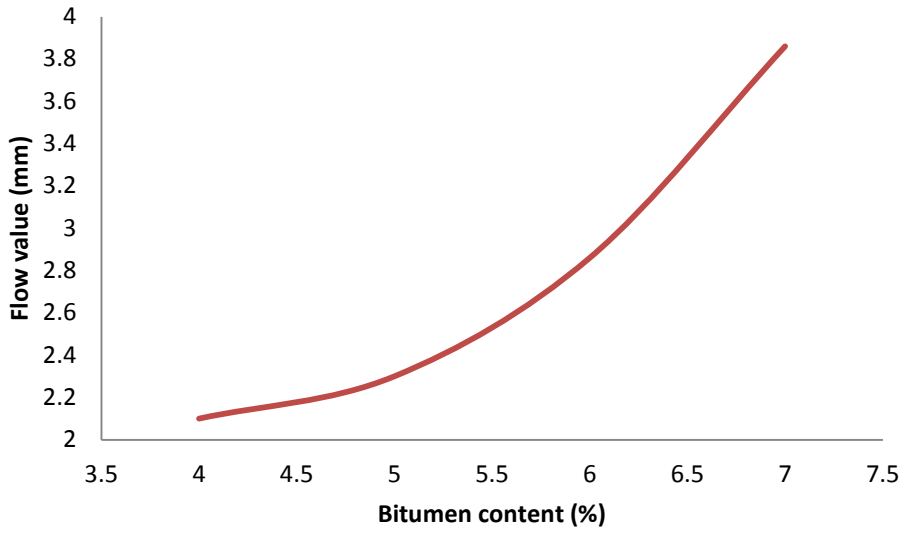

Fig 5.4: Average flow valuevs. Bitumen content for DBM samples

3. VMA vs. bitumen content: Values of VMA values in %ge and bitumen content in bitumen in %ge are plottedagainst binder in x-axis and VMA in y-axis.

- **Average VMA and Bitumen content for SMA samples**

BITUMEN CONTENT (%)	AverageVMA (%)
5	17.404
5.5	16.24
6	15.56
6.5	15.76
7	16.14

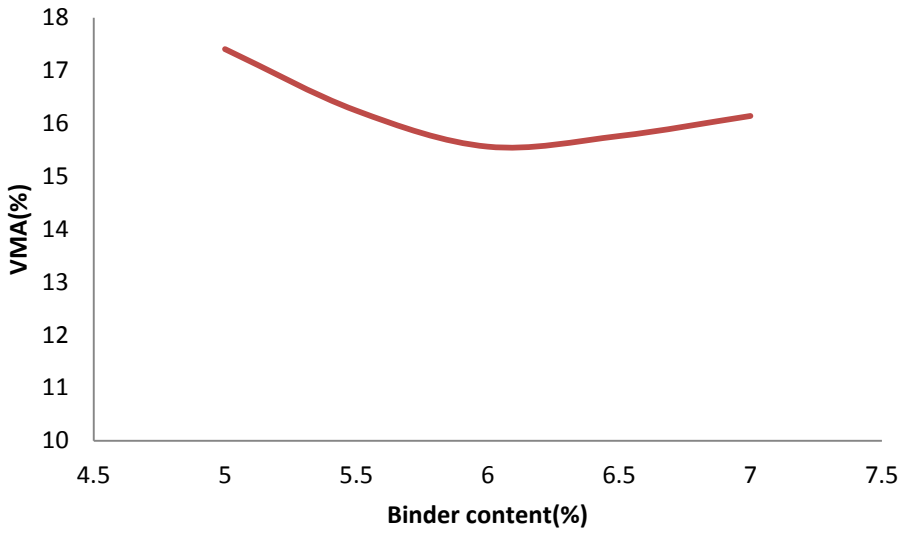

Fig 5.5: Average VMA vs. Bitumen content for SMA samples

- **Average VMA and Bitumen content for DBM samples**

BITUMEN (%)	AverageVMA (%)
4	16.16
5	13.86
6	13.96
7	14.38

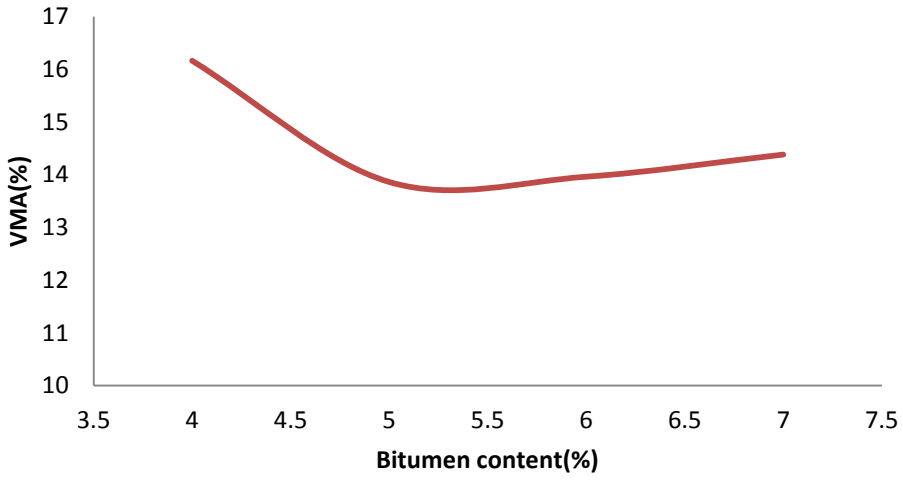

Fig 5.6 : Average VMA vs Bitumen content for DBM samples

5. VA vs. bitumen content: Values of VA values in %ge and bitumen content in bitumen in %ge are plottedagainst binder in x-axis and VA in y-axis.

- **Average VA and Bitumen content for SMA samples**

BITUMEN CONTENT (%)	Average VA (%)
5	6.231
5.5	4.72
6	3.781
6.5	3.287
7	3.09

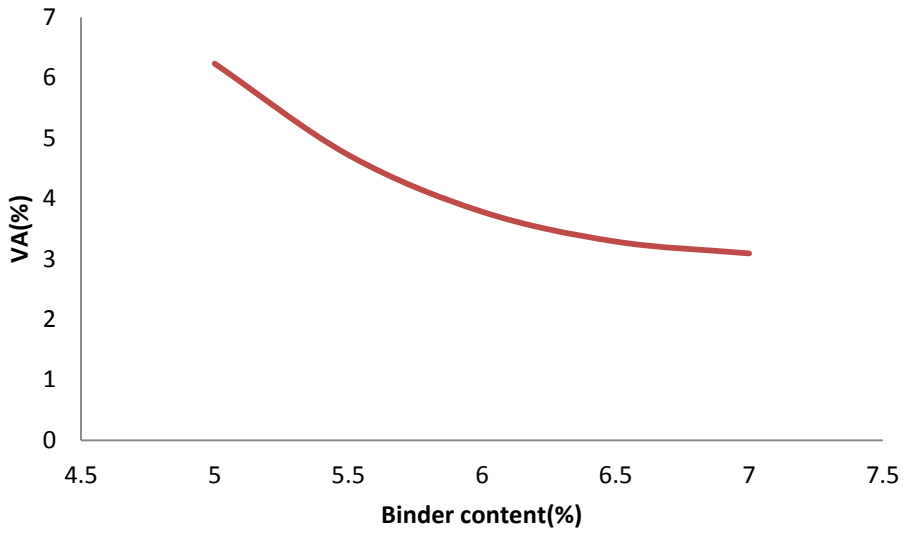

Fig 5.7 : Average VA vs Bitumen content for SMA samples

- **Average VA and Bitumen content for DBM samples**

BITUMEN (%)	Average VA(%)
4	5.83
5	4.12
6	3.09
7	2.78

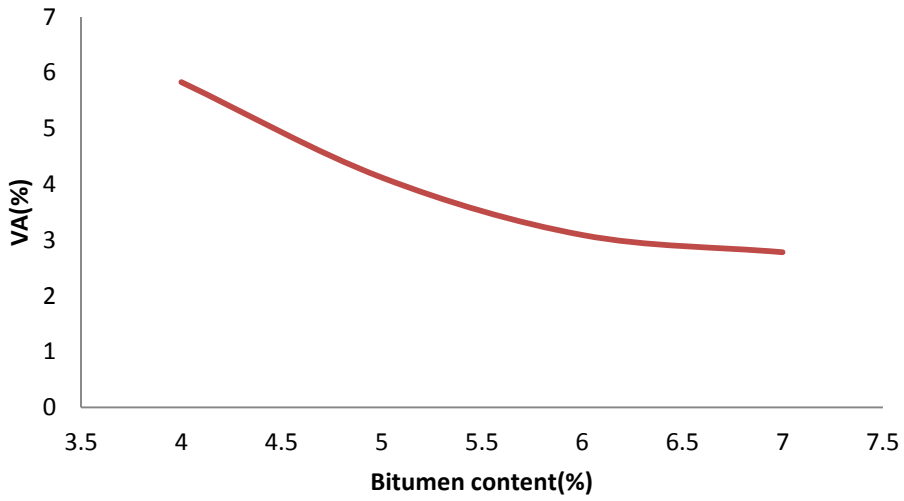

Fig 5.8 : Average VA vs Bitumen content for DBM samples

6. VFB vs. bitumen content: Values of VFB values in %ge and bitumen content in bitumen in %ge are plottedagainst binder in x-axis and VFB in y-axis.

- **Average VFB and Bitumen content for SMA samples**

BITUMEN CONTENT(%)	Average VFB(%)
5	65.023
5.5	68.76
6	71.86
6.5	73.88
7	74.988

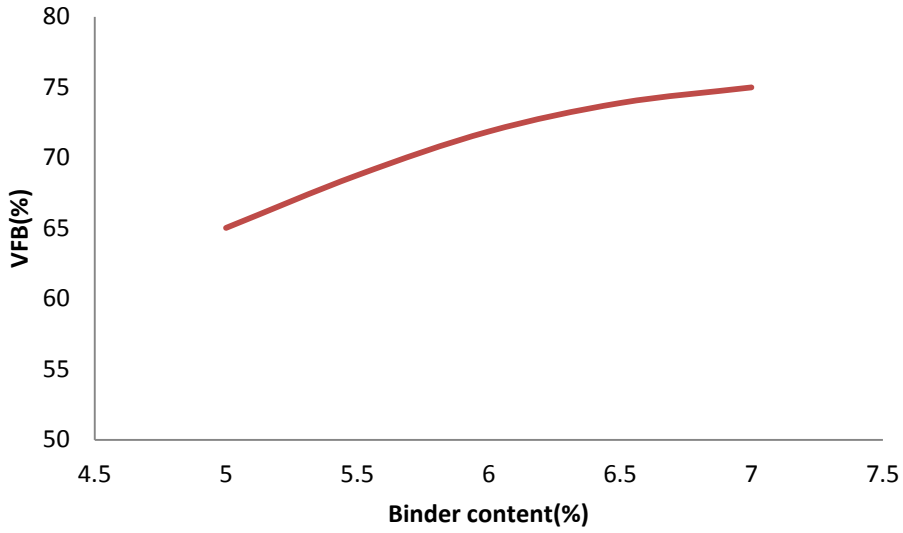

Fig 5.9: Average VFB vs Bitumen content for SMA samples

- **Average VFB and Bitumen content for DBM samples**

BITUMEN (%)	Average VFB(%)
4	63.86
5	68.23
6	70.89
7	72.09

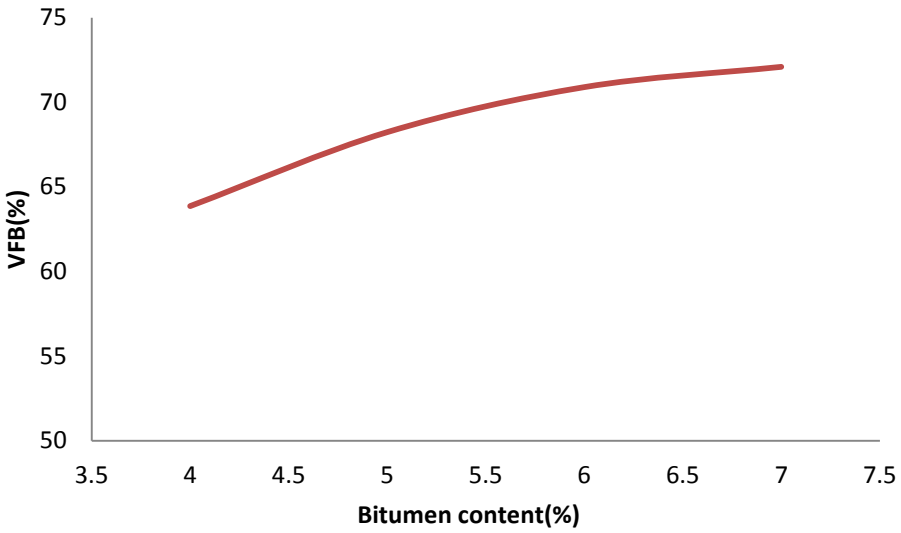

Fig 5.10 : Average VFB vs Bitumen content for DBM samples

7.Unitweight vs. bitumen content: Values of unit weight (Gmm) values in kg/m3 and bitumen content in bitumen in %geare plotted against bitumen in x-axis and Unit weight in y-axis.

- **Average unit weight and Bitumen content for SMA samples**

BITUMEN CONTENT (%)	Average unit weight(kg/m^3)
5	2401
5.5	2434.66
6	2485
6.5	2471
7	2437

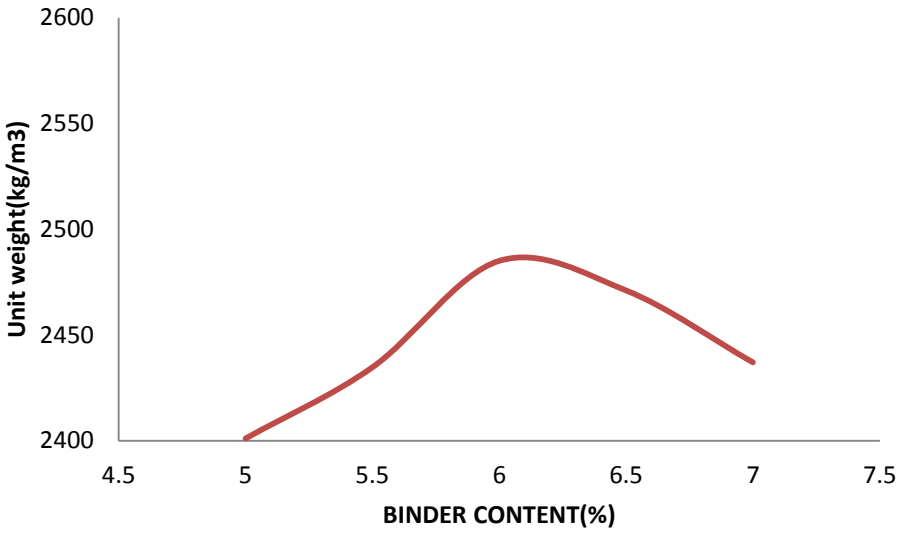

Fig 5.11: Average unit weight vs Bitumen content for SMA samples

- **Average unit weight and Bitumen content for DBM samples**

BITUMEN CONTENT(%)	Average unit weight(kg/m^3)
4	2437
5	2480
6	2546
7	2510

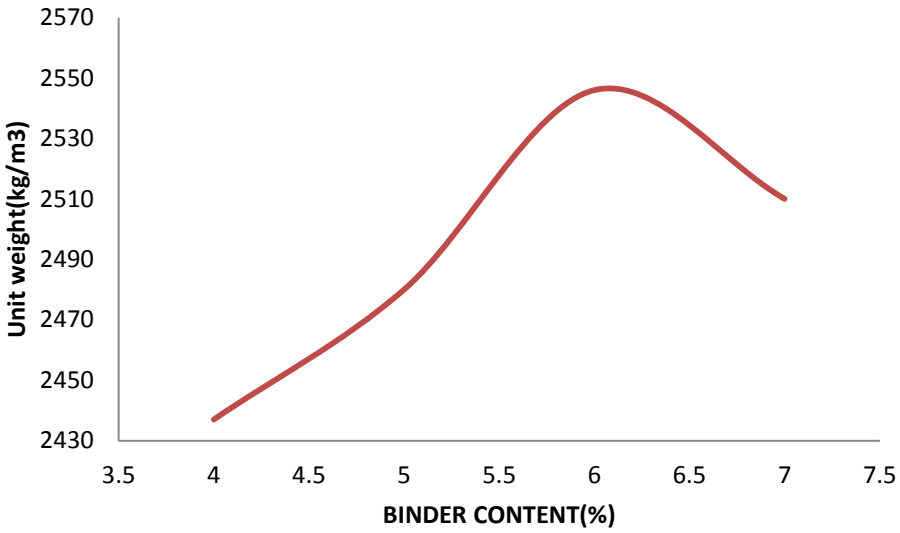

Fig 5.12: Unit weight vs Bitumen content for DBM samples

5.5 Discussions

- From the graphs, it is found that optimum binder content for SMA samples is 5.8% and for DBM samples it is 5.3%.
- Results and graphs obtained from Marshall Test indicate that stability is gradually increasing with increase in bitumen and emulsion content and then decreasing. Maximum stability is 13.17 KN for SMA mixes and 12.48 KN for DBM mixes.
- Flow value of SMA and DBM samples gradually increases with increase in bitumen content. The increase is slow initially, but later the rate increases with the increase in bitumen content.
- Theoretically VMA should remain constant for a given aggregate gradation with respect to binder content. But practically, it is observed that at low bitumen content, VMA slowly decreases with increase in bitumen content then increases after a pause.
- VA of Marshall samples decreaseswith increase in bitumen content and VFB increases with increase in bitumen content.

CHAPTER6

CONCLUSIONS

The conclusions which we have obtained from the experimentalstudy arepresented below.

>>The SMA samples were prepared using varying bitumen content of 4%,4.5%, 5%, 5.5% and 7% and DBM samples were prepared using bitumen content of 4%,5%,6% and 7% at a temperature of 110 ℃ . This was done to find out the effect of increasing bitumen content on the stability value. The plot obtained also helps us to find the Optimum binder content for this mix. The plot indicates that the stability value increases initially with increase in bitumen content but then decreases gradually.

>> The flow value increases with the increase in the bitumen content for both the mixes.The increase is slow initially for SMA samples, but later the rate increases with the increase in the bitumen content. For DBM samples, the flow value gradually increases with increase in bitumen content. As the bitumen content increases the homogeneity is lost , due to which lumps are formed,which makes the sample loose its homogeneity, reducing stability and increasing deformation under load.

>>With increase in bitumen content, VA of SMA and DBM sample both decreases, as bitumen replaces theair voids in the mix and subsequently, VFB increases with increase in bitumen content.

>>Theoretically VMA should remain constant for a given aggregate gradation with respect to binder content. Practically it is observed that at lower binder content, VMA slowly decreases then increases after a pause.This happens for both the mixes. The initial fall in VMA is due to re-orientation of aggregates in presence of bitumen. In present case it is seen that VMA increases as binder increases. This may be explained by argument that due to thicker bitumen film, the aggregates move apart resulting in increase of VMA.

CONCLUDING REMARKS

In this study SMA and DBM Mixes were prepared where VG 30 bitumen was used as binder. Optimum binder content of both the mixes was obtainedby using Marshallmix design by adding synthetic zeolite as additiveat 0.3% by weight of aggregate mix. Optimum binder content is selected as the average binder content for maximum unit weight, maximum stability and specified percent air voids in the total mix. The optimum binder content of WMA samples of **SMA and DBM** mix is found to be 5.8**%**and **5.3%** respectively.

FUTURE SCOPE:

>>In future performance of WMA with other grades of bitumen can also be tested and seen whether it can be used successfully or not.

>>Other fillers such as rock dust; slag dust etc. can be used to prepare WMA samples of SMA and DBM.

>>WMA samples can be prepared at other temperatures and their performances can be evaluated.

>> Indirect tensile test of SMA and DBM bituminous mixes can give us an idea about tensile strength of bituminous mixes.

>>Repeated load test can give us idea about the fatigue failure resistance ofthe specimen.

>>Wheel tracking test can give us idea about the rut resistance of the specimen.

REFERENCES

1. ASTM D 1559 (1989), "Test Method for Resistance of Plastic Flow of Bituminous MixturesUsing Marshall Apparatus".

2. Chakraborty, Partha, Das Animesh, Principles of transportation engineering, PHI 2003, page no 294-299.

3. D'Angelo, J., Harm, E., Barloszek, J., Baumgardner, G., Carrigan, M., Cowsert, J. Warm-Mix Asphalt: European Practice. Alexandria, VA: Federal Highway Administration, 2008. FHWA-PL-08-007.

4. Gandhi, T.S. and Amirkhanian, S.N., (2007), "Laboratory Evaluation of Warm Asphalt Binder Properties – A Preliminary Analysis", 5th International Conference of Maintenance and Rehabilitation of Pavements and Technological Control, Park City, Utah, pp 475-480.

5.Georgiev D., Bogdanov B., Angelova K., Markovska I., Hristov Y.,2009, " Synthetic zeolites - structure, classification, current trends in zeolite synthesis", Review report, International Science conference, Stara Zagora, Bulgaria.

6. Goh, S.W., Zhanping, Y., Van Dam, T.J., 2007, "Laboratory Evaluation and Pavement Design for Warm Mix Asphalt", 2007 Mid-Continent Transportation research Symposium, Ames, Iowa,pp-17-35.

7. Hodo, W. D., Kvasnak, E., and Brown, E. R. (2009). ―Investigation of Foamed Asphalt (Warm Mix Asphalt) with High Reclaimed Asphalt Pavement (RAP) Content for Sustainment and Rehabilitation of Asphalt.‖ Transportation Research Board 2009 Annual Meeting, Washington, D.C.

8. Hurley, G.C. and Prowell, B.D. Evaluation of Asphamin for use in Warm Mix Asphalt. Auburn, Alabama: National Center for Asphalt Technology, 2005. NCATReport 05-04.

9. Hurley, G.C. and Prowell, B.D. Evaluation of Sasobit for use in Warm Mix Asphalt. Auburn, Alabama: National Center for Asphalt Technology, 2005. NCAT Report 05-06.

10. Hurley, G.C. and Prowell, B.D. Evaluation of Evotherm for use in Warm Mix Asphalt. Auburn, Alabama: National Center for Asphalt Technology, 2005. NCAT Report 06-02.

11. Hurley, G., and Prowell, B., (2006), "Evaluation of Potential Process for use in Warm Mix Asphalt", Journal of the Association of Asphalt Paving Technologist, Volume 75, pp 41 – 90.

12. BIS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P - I): Particle Size and Shape", Bureau of Indian Standards, New Delhi

13. BIS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P-III): Specific Gravity, Density, Voids, Absorption, Bulking", Bureau of Indian Standards, New Delhi

14. BIS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P-IV): Mechanical Properties", Bureau of Indian Standards, New Delhi

15. Khanna S.K. and Justo C.E.G. (2001), "Highway Engineering", Nem Chand and Bros, Roorkee, pp315-321.

16. Kunnawee, K., Samak, S., Kitae, K., Wilfung, M., &Hussain, B. , "LaboratoryStudy on Warm Asphalt Additives . Washington D.C.: Transportation Research Board,2007.

17. Lee, S.J.; Amirkharian, S.N.; Park, N. –W.; Kim, K.W, 2009. Characterization of warm mix asphalt binders containing artificially long – term aged binders, Construction and Building Materials, pp. 30-43.

18.Lee, H., Kim, K., Hwang, S., &Jeong, K. Use of Warm Mix Asphalt Additives for Cold In-place recycling using Foamed Asphalt. Park City, Utah: InternationalConference on Maintenance and Rehabilitation of Pavements and TechnologicalControl, 2007

19. PandaN,"Laboratory investigations of stone matrix asphalt using sisal fibre for Indian roads "Btech project report Nit Rourkela, 2010.pp23 - 36.

20. Prowell, B.D., Hurley, G.C. and Crews, E. Field Performance of Warm Mix Asphalt at the NCAT Test Track. Washington D.C.: Transportation Research Board, 2007.

21.Sampath Anand, "Compressive evaluation of four warm mix asphalt mixtures regarding viscosity, tensile strength, moisture sensitivity , dynamic modulus and flow number" University of Iowa , May 2010, pp.8-11.

22. Wielinski, J., Hand, A., and Rausch, D. M. (2009). ―Laboratory and Field Evaluations of Foamed Warm Mix Asphalt Projects.‖ Transportation Research Board 2009 Annual Meeting, Washington, D.C.